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ABSTRACT

Provincial water quality objectives have been established for the protection of aquatic life and for recreation. The hydrologic characteristics have dominant effects on the ability of the streamflow to assimilate wastewater to meet the provincial water quality objectives. Extreme low streamflows are used to establish design flow criteria for receiving water assessments. Further, the effects of drought on streamflows are considered by evaluating performances in satisfying design flows with regards to possible impacts on water quality protection. A statistical method has been used to characterize the drought flows which allows grouping into probable critical drought flows areas. The performances of the rivers were examined by considering failures to satisfy water quality requirements, the capability of the river to recover from failure and the extent of the consequences of failures. The performances of river systems in response to extreme low flows are compared among locations in Ontario.

INTRODUCTION

Several rivers in Ontario are used to assimilate treated wasteloads. Man made wastes include point source discharges from municipal and industrial plants and diffuse sources in runoffs. These waste sources may have major impacts to the water quality. Safe water quality is necessary for a viable aquatic life and to provide stream conditions which are free of risk to human health.

The Ontario Ministry of the Environment has the responsibility to protect the environment from degradation (Government of Ontario 1975, 1980, 1980). Guidelines and objectives have been established for water quality protection (Ontario Ministry of the Environment 1979, 1980, 1983); particularly, to protect and improve the quality of streams and lakes that have been degraded and to minimize the risk of failure in flows for wastewater assimilation.

The hydrological conditions influence the capability of the river to assimilate wastes. Droughts, in particular, are critical to waste assimilation. Similarly, the physiographic and hydrogeologic characteristics vary in nature in Ontario (Chapman and Putman 1966) and subsequently influence the streamflow yields which are natural sampling of the water availability.

The provincial streamflow yields belong to a spatial and definite probability distribution. In addition, the time series of extreme low flows belong to a separate and different probability distribution. A number of non-parametric probability distributions have been investigated for extreme low flows (Gumbel 1958, 1963; Matalas 1963). A comparative evaluation of probability distributions for extreme low streamflows in Ontario were investigated by Condie and Nix (1975). The Ministry of the Environment has analysed extreme low flow time series in Ontario to establish design flows for wastewater assimilation (OMOE 1973, 1974, 1975, 1976, 1977). Further investigation has evaluated the suitability of an acceptable risk of failure to set guidelines for design flows (Logan 1982, 1984).

The objectives of this paper are to evaluate extreme low flows with respect to meeting the needs of instream quality assessment and to evaluate the performance of the river system in terms of the streamflow reliability, resiliency and vulnerability.

DROUGHT FLOW DESIGN

The Provincial streamflow yield, being spatial in nature, is assumed to be normally distributed: N [μ, σ] with confidence bounds about the population average, μ , defined as:

[1] $$\bar{X} - t_\alpha S_{\bar{X}} \leq \mu \leq \bar{X} + t_\alpha S_{\bar{X}}$$

where, $\bar{X}$ and $S_{\bar{X}}$ denote the sample average and standard error of average respectively; t_α denotes the standard deviate with α the significance level.

The extreme low flow event, on the other hand, is defined as the minimum consecutive m-day average low flow in any given year:

[2] $$\bar{X}(m)_j = \min [\bar{X}(m)_{i,j}]$$

where, $X(m)_j$ and $X(m)_{i,j}$ denote the consecutive m-day average extreme low flow in year, j and the consecutive m-day moving average flow at period, i, in year, j, respectively.

The time series of extreme low flows, $X(m)_j$, j = 1,2, ..,N, at a given site, is assumed to be Gumbel Extremal Type 3 distributed (Gumbel, 1963):

[3] $$f(x) = \left[\frac{a}{x_o - e}\right] \left[\frac{x - e}{x_o - e}\right]^{a-1} \exp -\left[\frac{x - e}{x_o - e}\right]^a$$

where, x_o is the characteristic drought flow; a is the scale parameter, (equivalent to standard deviation); and e is the lower boundary value; and with

$x_o \equiv \bar{X}_o(m)_j$ and $x \equiv \bar{X}(m)_{i,j}$ are defined.

Integration of eq. [3] from e to x produced the cumulative probability distribution:

$$[4]\quad P(x) = e^{-y}$$

$$\text{where, } y = \left[\frac{x - e}{x_o - e}\right]^a$$

A drought flow design, mQ_T, can be specified from the fitted probability model, eq. [3]. The risk of failure T (return period) is set by the decision-maker or from guidelines. An acceptable design condition is subjected to a specified water quality objective (OMOE 1980).

Parameter Uncertainties

Uncertainties are imbedded in the sample estimates of the probability model parameters, x_o,a, and e (eq.[3]). A computer intensive non-parametric technique (Efron and Gong 1983; Logan and Unny 1985) is used to investigate these uncertainties.

The procedure involved fitting the extreme low flow events, x_j,j = 1, 2, .., N, to the probability model, to determine estimates of x_o, a, and e. By applying the Monte Carlo resampling procedures implicit in the Boothstrap's approach, several realizations of x_o, a, and e can be determined. Frequency analyses of the realizations of the parameter sets provide the joint empirical distributions which describe the uncertainties associated with these parameter estimates.

Wasteload

Site specific design flows for wasteloads have been investigated by Biswas and Bell (1984). They have considered a design flow to satisfy chronic and acute values of pollutants. For protection against chronic value, the wasteload, W_c, at a site, is proportional to the total flow times the concentration of the pollutant:

$$[5]\qquad W_c \propto (mQ_T + Q_c)\, C_c$$

where, W_c is the chronic wasteload; mQ_T is the design low streamflow; Q_c and C_c are the effluent flow and concentration, respectively.

The non-conservative pollutants, example, BOD and other wastes, depend on pH and temperature for microbial breakdown of the biological matters; hence to determine the chronic wasteload, W_c, an empirical water quality model analysis is required to relate flow and waste (OMOE 1976, 1977). For this study it is assumed that once the W_c is determined, this effluent disposal can be controlled, in time, so as not to be exceeded. There is, however, chances of violation of the specified water quality objective due to stochastic variability in streamflow. This implies that the non-violation of the water quality objective is conditional on the ability of the river to satisfy the design flow requirement at all times. Logan (1984) investigated risks of failure in water quality considering stochastic variabilities in both streamflow and quality. This paper will consider only streamflow performance with implication and inferences on likely risk of failure in water quality.

STREAMFLOW PERFORMANCE

If the streamflow events over time period of N years are such that the targetted drought flow design, mQ_T, is satisfied at all times and the chronic wasteload, W_c, discharged is not being exceeded, then the streamflow system is reliable.

Hashimoto et al (1982) developed concepts for evaluating system performance based on reliability, resiliency and vulnerability. Fiering (1982) quantified the system resiliency by considering how quickly a system can recover from failure once a failure occurred. He further expanded this to the severity of failure once failure occurred which he defined as vulnerability.

Reliability of the system is the probability, α, that the system is in a satisfactory state, S,:

[6] $$\alpha = P\,[X_t \in S]$$

where, X_t denotes the streamflow at time t.

The degree to which the system recovers once a failure occurred is the resiliency:

[7] $$\gamma = P[X_{t+1} \in S\ ;\ X_t \in F]$$

where, F denotes that the system is in a failure state.

The system operates in transition from a satisfactory to a failure state and vice versa.

Let $Z_t = 1$, if $X_t \in S$; and $Z_t = 0$, if $X_t \in F$; hence

the fraction of the time the system is satisfactory is:

[8] $$T_S = (1/n) \sum_{t=1}^{n} Z_t$$

In the long run as $n \to \infty$, satisfaction approaches the system reliability:

[9] $$\lim_{n \to \infty} 1/n \sum_{t=1}^{n} Z_t = \alpha$$

Consider the process of transition:

Let $W_t = 1$, if $X_t \varepsilon S$ and $X_{t+1} \varepsilon F$; and $W_t = 0$, otherwise.

Similarly, in the long run as $n \to \infty$, the average value of W_t approaches the probability, ρ, of the system being in the state, S, and transferring to the failure state, F, in the following period:

[10] $$\rho = \lim_{n \to \infty} 1/n \sum_{t=1}^{n} W_t = P[X_t \varepsilon S; \; X_{t+1} \varepsilon F]$$

where, ρ is the probability in transition. The average time in temporary resident in the unsatisfactory state, F, during a n-period is:

[11] T_F = (total time spent in F)/(number of times F occurred)

Hence:

[12] $$T_F = [1/n \sum_{t=1}^{n} (1-Z_t)] \,/\, [1/n \sum_{t=1}^{n} W_t]$$

$$= (1- \alpha)/\rho$$

By definition, resiliency, γ, is the reciprocal of $E[T_F]$; therefore with $n \to \infty$:

[13] $$\gamma = \rho/(1-\alpha) = P[X_t \varepsilon S; X_{t+1} \varepsilon F]/P[X_t \varepsilon F]$$

Further, as $n \to \infty$ the expected number of transition from S to F is equal to the expected number of transition in the reverse direction:

[14] $$P[X_t \varepsilon S; X_{t+1} \varepsilon F] = P [X_t \varepsilon F; X_{t+1} \varepsilon S]$$

This implies that γ is equivalent to the average probability of recovery from the failure, F, in a single time step:

[15] $$\gamma = P[X_t \varepsilon F; X_{t+1} \varepsilon S]/P [X_t \varepsilon F]$$

$$= P[X_{t+1} \varepsilon S \parallel X_t \varepsilon F]$$

Vulnerability is a measure of the severity of a failure in a system and, as such, defines the magnitude of the failure. This could either be in terms of intensity and duration. Although a system may not likely to fail it is, however, still vulnerable.

Let X_t be the discrete failure-flow of the system output, that is, $X_t \varepsilon F$; and let D_k denotes the severity or the degree of failure assigned to each failure. In drought flow periods, a low intensity long duration failure is considered to be as important, as a high intensity short duration failure, given that an equivalent short fall quantity is experienced for each failure occurrence. Therefore, the degree of failure, D_k, due to the occurrence of a failure on any single day, t, is expressed in terms of the deficit between the system requirement and the prespecified design flow, mQ_T, desired for the wastewater assimilation, that is, using both intensity and duration to define failure gives:

$$[16] \quad D_k = (mQ_T - X_k) \Delta t/A$$

where, Δt is the period between t and (t + 1), A is a constant used to standardize D_k; and k is the time step of the severe failure-flow.

Further, define h_k as the probability that a discrete failure, X_k, is the most severe outcome that occurs within the set of failure states. Then vulnerability of the system, v, is specified by:

$$[17] \quad v = \sum_{k=1}^{L} h_k D_k$$

where, k = 1, 2, ..., L is the number of severe failure-flow events.

Trade-offs between system resiliency and vulnerability is an important factor in decision making with regards to operational policies.

APPLICATION

There are approximately 505 gauged streamflow locations in Ontario. These streams are surveyed by the Water Survey of Canada; with published records issued annually (WSC 19XX). The stations are identified by Drainage Basin Boundary as shown by examples in Figure 1.

Sets of average annual flows at 233 natural and 272 regulated stations indicated Normal Distributions as shown in Figure 2(a); with the provincial yields and standard errors of 0.0111 ± 0.0002 $m^3/s/km^2$ and 0.0117 ± 0.0002 $m^3/s/km^2$ for the natural and regulated sites, respectively.

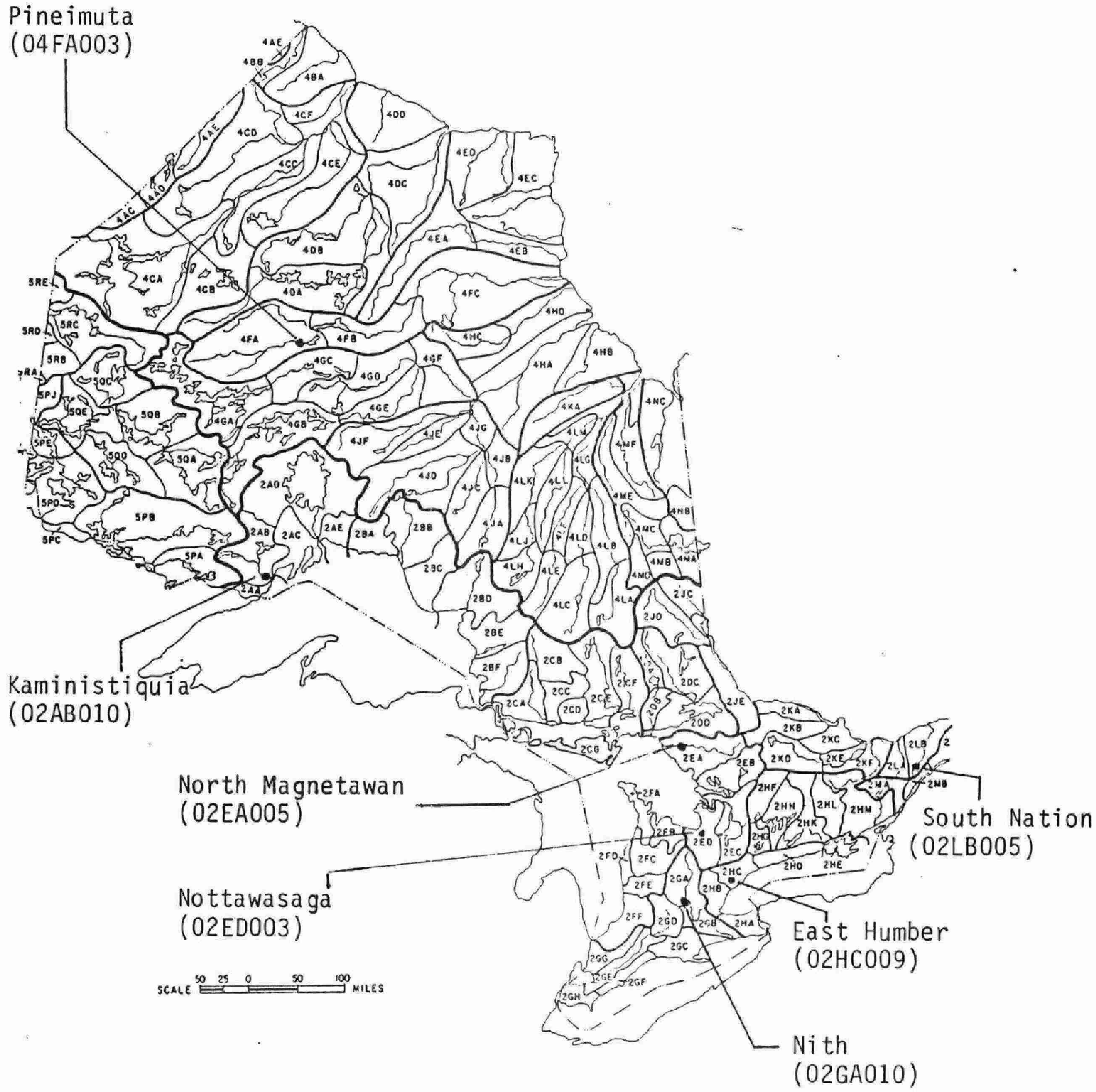
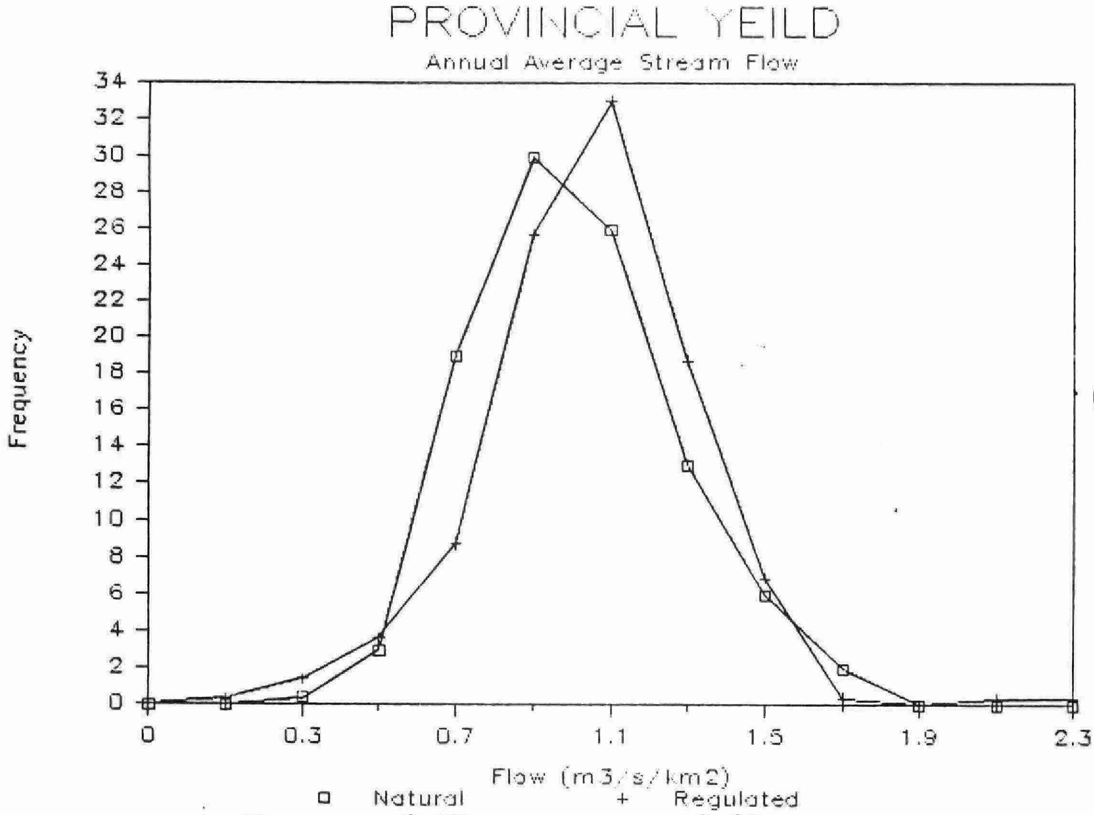
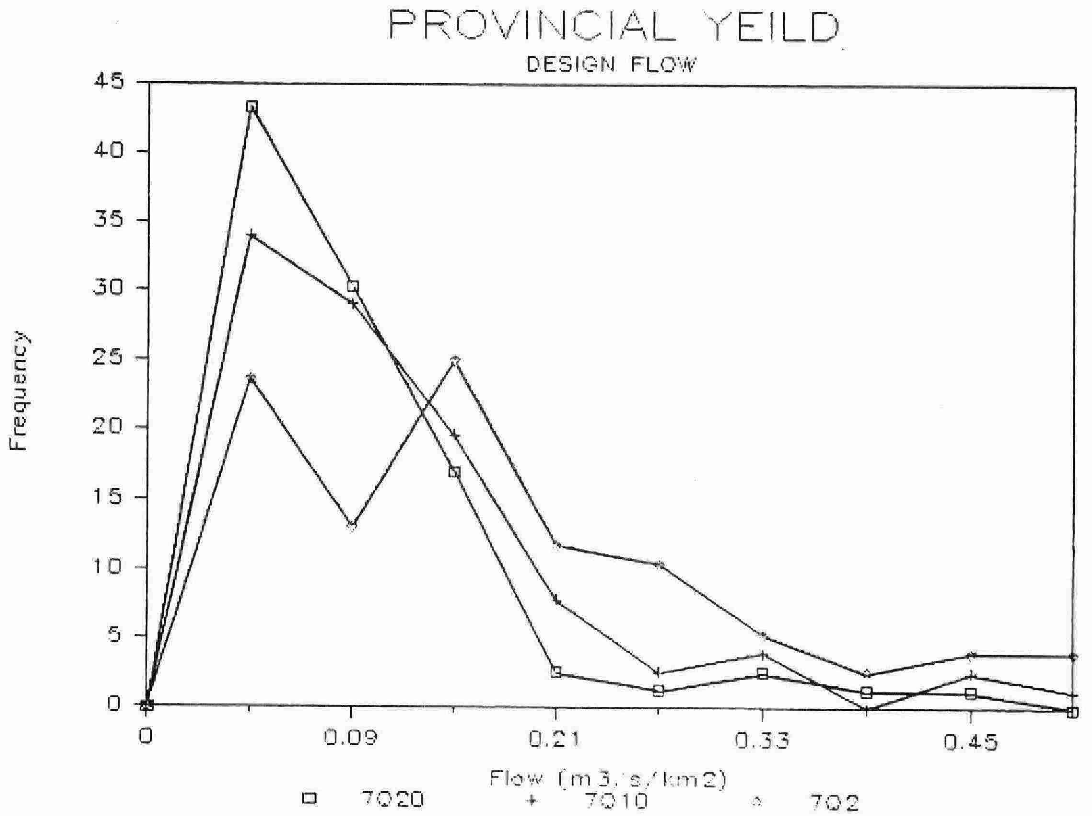


Figure 1. Ontario: Examples of Streamflow Station Location.



(a)

Skew - 0.38 - 0.06



(b)

Skew - 2. - 2. - 1.

Figure 2. Distribution of Streamflow Yeilds in Ontario.

Frequency analysis of extreme low flows at gauged stations with records greater than 10 years produced results at 76 natural and 111 regulated stations (OMOE 1973, 1974, 1975, 1976, 1977). Spatial frequency analysis for design low flows: $7Q_2$, $7Q_{10}$ and $7Q_{20}$ demonstrated skewed distributions (Figure 2(b)). The skewness increases negatively with an increase in the return period. Further spatial analysis of design low flow yields, on a regional basis, showed noted difference in average yields between the southern and the northern regions of the province (Table 1). The southwest region has yields which are significantly lower than the provincial average yields, implying greater probability for susceptibility to severe drought. On the other hand, the northern, northeast and central regions appear to be less susceptible to drought; in that, they are of. expected higher streamflow yields which appeared to be consistent with the natural yields of the hydrogeological condition of those areas. The spatial yield values are shown only for comparative purposes and should not be used in design.

Characteristic drought flows frequency curves at selected streamflow locations for defined consecutive m-day drought sequences, calculated for the time period 1960-1984, are shown in Figure 3(a). The rivers in the north and central Ontario (example, Kaministiquia and North Magnetawan) display higher drought yields as compared to the south (example, East Humber and South Nation). Other examples of site specific drought flow frequency curves are shown in Figures 3 (b). Additional frequency curves for drought flows can be derived with the use of the values listed in Table 2. Unlike the regional low flows, the stations' drought flow frequency curves can be used for design purposes.

The parameters: characteristic drought flow, X_0, and scale parameter,a, are examined for uncertainties using the Boothstrap computer intensive statistics. In this example, the minimum daily flows are fitted to the Gumbel (Fisher-Tippett Type 1) distribution. The Monte Carlo resampling approach in 1000 Boothstrap iterations produced the joint distributions for X_0 and a as shown in Figure 4 for selected rivers. These joint distributions are bounded and appeared to be inherently Normal. Each pair of parameters (X_0 and a) of the empirical distributions can be used to generate a series of low flows which are utilized in further risk analysis of a separate study.

The reliability of a river is its capability to satisfy a target or design flow, mQ_T, at a site on a daily basis, while resiliency measures are the probability that the river will recover from failure in time immediately following the time the failure occurred. In fact, a failure is said to occur when the output violates a specified performance threshold. If a failure in mQT occurred at a control site, it is then implied that a water quality violation will occur. If the failure is of a considerable duration, in terms of consecutive days of non-exeedence in mQ_T, then the impact on water quality violation could be insurmountable.

The Ministry of the Environment's Policy is a consecutive 7-day average low flow at a 5 percent risk of failure ($7Q_{20}$). It is implied that non-exceedences of the design flow will cause water quality violation in BOD and other wastes. Vulnerability gives a measure of the severity or magnitude of this failure.

TABLE 1: AVERAGE YIELD FOR DESIGN FLOW: ONTARIO

DESIGN FLOW POLICY	CENTRAL	SOUTHWEST	SOUTHEAST	NORTHEAST	NORTHERN	PROVINCE
		[Flow yield $(m^3/s/km^2)$ $.10^{-3}$]				
$7Q_{20}$						
$\bar{X}$	1.0	0.8	0.4	0.8	1.4	1.1
$S_{\bar{X}}$	0.3	0.3	0.2	0.2	0.2	0.1
$7Q_{10}$						
$\bar{X}$	1.1	0.9	0.6	1.0	1.6	1.3
$S_{\bar{X}}$	0.3	0.3	0.3	0.2	0.2	0.1
$7Q_2$						
$\bar{X}$	1.8	1.3	1.7	2.1	2.2	1.9
$S_{\bar{X}}$	0.4	0.3	0.8	0.4	0.3	0.2

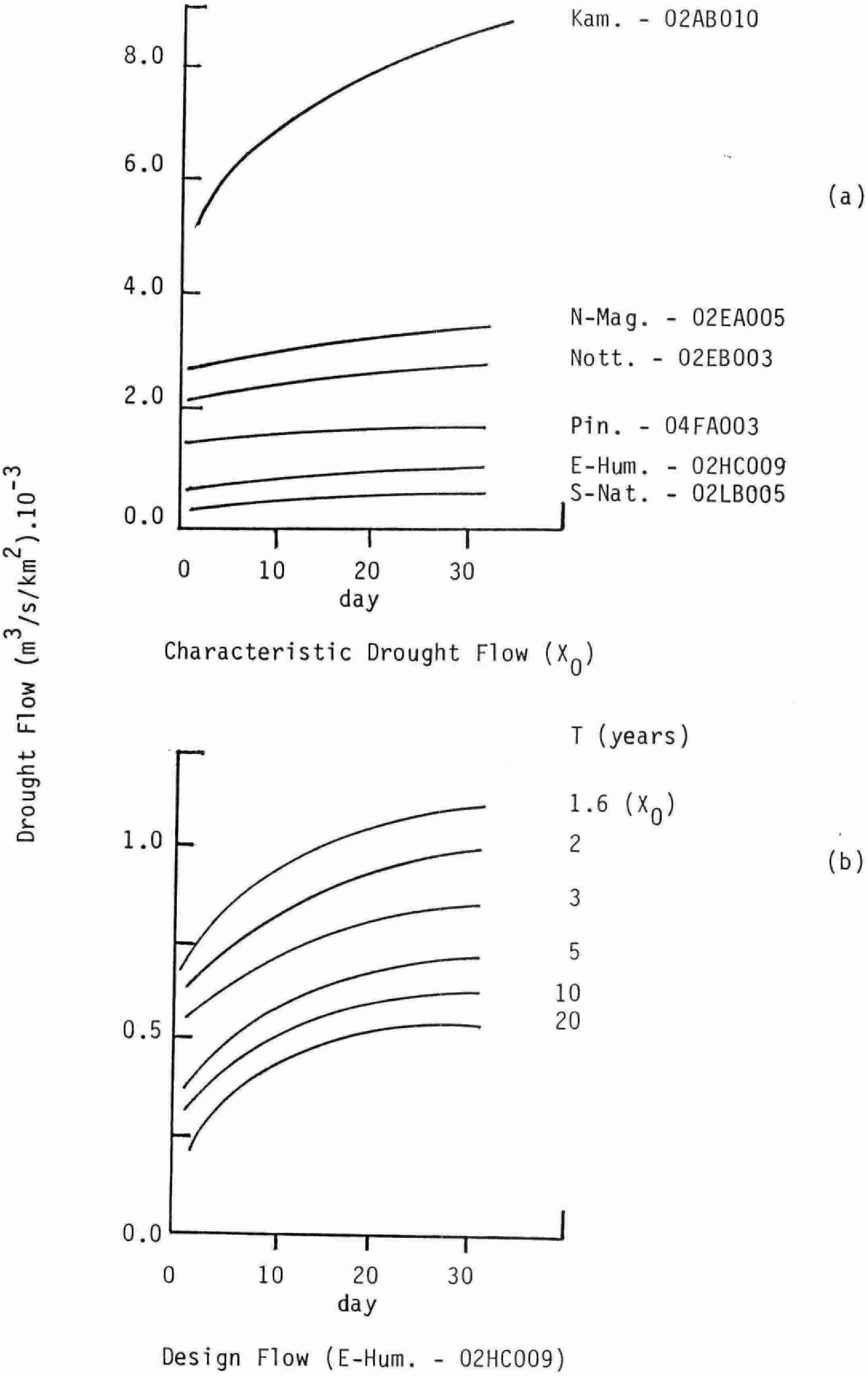


Figure 3. Drought Flow Frequency Curves

TABLE 2: DROUGHT FLOWS AT SPECIFIED RETURN PERIODS

DROUGHT SEQUENCE/		KAM.	PIN.	N-MAG.	NOTT.	E-HUM.	S-NAT.
			[Flow Yield ($m^3/s/Km^2$).10^{-3}]				
1-Day:	7Q2	4.60	1.44	2.55	1.89	0.65	0.24
	7Q10	1.68	0.94	0.90	1.22	0.25	0.11
	7Q20	1.40	0.84	0.60	1.12	0.14	0.10
3-Day:	7Q2	4.84	1.40	2.62	1.96	0.72	0.27
	7Q10	2.74	0.94	0.96	1.46	0.42	0.11
	7Q20	2.29	0.84	0.63	1.30	0.36	0.10
7-Day:	7Q2	5.77	1.40	2.78	2.03	0.77	0.28
	7Q10	3.54	0.94	1.06	1.52	0.47	0.15
	7Q20	3.06	0.84	0.69	1.37	0.41	0.14
15-Day:	7Q2	6.44	1.41	2.98	2.17	0.84	0.33
	7Q10	4.15	0.95	1.28	1.63	0.52	0.17
	7Q20	3.70	0.85	0.92	1.49	0.45	0.16
30-Day:	7Q2	7.39	1.44	3.12	2.36	1.00	0.42
	7Q10	4.55	0.99	1.54	1.75	0.64	0.18
	7Q20	3.94	0.90	1.12	1.62	0.54	0.15

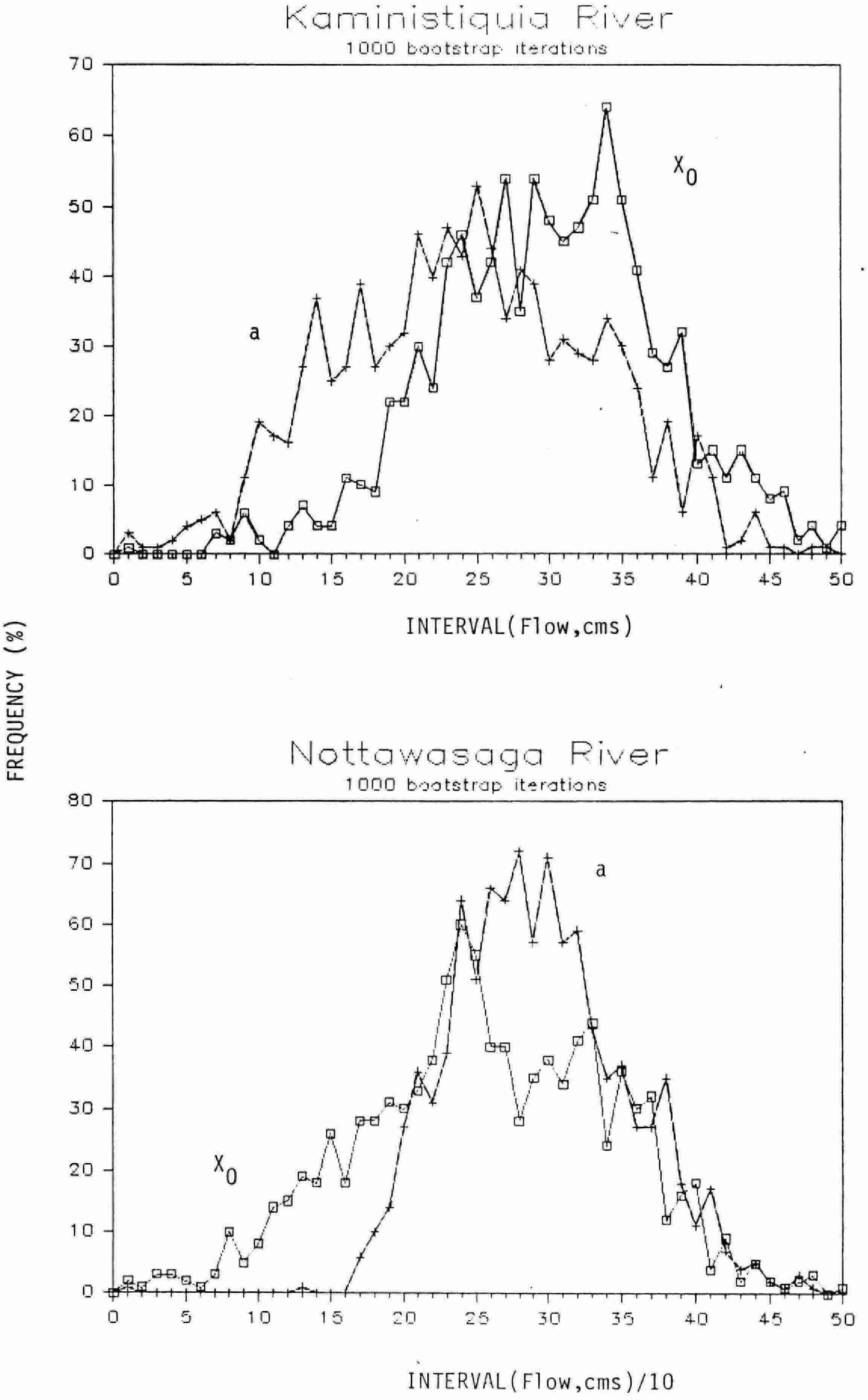


Figure 4. Non-parametric Probability Distributions for Site Specific Characteristic Drought Flow, X_0, and Scale Parameter, a.

The characteristic drought flows relate to the greatest impacts a defined drought sequence may have at a site should an impending drought occur. The performance of a river is evaluated by examining the reliability, α, resiliency, γ, and vulnerability, v. Table 3 shows the performance evaluations based on the characteristic drought flows at selected rivers in Ontario. Graphical descriptions are shown in Figure 5. The vulnerabilities appeared to be marginal for defined drought sequences up to the 30-day average. These are due to the low flow deficits experience during failure days. The resiliencies are, however, very critical, resulting in extended duration of consecutive days of failure, once failure occurred. Eventually, these failures will have a major impact on the water quality. The stations: Nottawasaga, Humber and South Nation rivers displayed similar performances, implying high reliability, marginal vulnerability and concerned cases of resiliency. The Pineimuta and Kaministiquia rivers, on the other hand, demonstrated a greater measure of vulnerability, while the resiliencies remain critical. The station North Magnetawan showed high reliabilities and with resiliency values ranging from 0.027 to 0.026; implying a range of 37 to 39 consecutive days of failure, for defined 1-day to 30-day average drought, once a failure does occur. The Nith River showed a similar performance of implied duration of 25 to 36 consecutive day of failure once a failure occurred; and of lesser reliability.

For design purposes in satisfying wastewater assessments, the magnitude of acceptable performance of the river, mainly resiliency, should be enhanced. Performance evaluations based on drought flow designs: $7Q_2$, $7Q_{10}$ and $7Q_{20}$ demonstrated significant improvement on satisfying performance requirement. Table 4 shows values for α, γ and v at selected sites. Figure 6 displays the characteristic performance curves. Reliabilities in all cases are high, resiliencies are of acceptable value, indicating reduction in duration of consecutive days of failure once failure occurred. In general, resiliency and vulnerability in comparison to the characteristic drought flows are at higher efficiency, but are at lower improvement between policies $7Q_2$ and $7Q_{10}$; however, performances between policies $7Q_{10}$ and $7Q_{20}$ are at acceptable levels implying high reliability, moderate resiliency (reduction of consecutive days of failure once failure occurred) and negligible vulnerability. Suitable management practice could best be evaluated for meaningful trade-off between γ and v.

TABLE 3: PERFORMANCE EVALUATION OF RIVER SYSTEM UNDER CHARACTERISTIC DROUGHT FLOWS

STREAMFLOW STATION	SEQUENCE (-day)	FLOW ($m^3/s/Km^2$) 10^{-3}	RELIABILITY	RESILIENCY (T^{-1})	VULNERABILITY (m^3)	CONSECUTIVE FAILURE DAYS
KAMINISTIQUIA (02AB010)	1	4.78	0.98	0.281	0.11	4.
	3	5.48	0.95	0.138	0.28	7.
	7	6.47	0.91	0.055	2.23	18.
	15	7.19	0.88	0.046	3.98	22.
	30	8.29	0.84	0.043	5.83	23.
NORTH MAGNETAWAN (02EA005)	1	3.08	0.93	0.027	0.33	37.
	3	3.15	0.92	0.028	0.32	36.
	7	3.30	0.91	0.028	0.35	36.
	15	3.49	0.91	0.026	0.42	39.
	30	3.64	0.90	0.026	0.45	39.
NOTTAWASAGA (02ED003)	1	2.02	0.95	0.102	0.04	10.
	3	2.07	0.94	0.094	0.05	11.
	7	2.16	0.92	0.078	0.05	13.
	15	2.31	0.89	0.056	0.11	18.
	30	2.55	0.83	0.034	0.33	30.
EAST HUMBER (02HC009)	1	0.74	0.94	0.107	0.001	9.
	3	0.84	0.92	0.075	0.002	13.
	7	0.85	0.91	0.055	0.003	18.
	15	0.94	0.87	0.048	0.004	21.
	30	1.10	0.80	0.037	0.008	27.
SOUTH NATION (02LB005)	1	0.30	0.94	0.060	0.06	17.
	3	0.31	0.93	0.051	0.75	20.
	7	0.35	0.92	0.040	0.13	25.
	15	0.42	0.90	0.033	0.28	30.
	30	0.53	0.85	0.025	0.72	40.
PINEIMUTA (04FA003)	1	1.52	0.92	0.020	3.51	50.
	3	1.53	0.92	0.020	3.66	50.
	7	1.54	0.91	0.019	3.73	51.
	15	1.55	0.91	0.019	3.90	51.
	30	1.58	0.91	0.019	3.78	51.
NITH (02GA010)	1	2.22	0.91	0.040	0.06	25.
	3	2.23	0.90	0.039	0.07	26.
	7	2.29	0.89	0.032	0.10	31.
	15	2.41	0.86	0.031	0.12	32.
	30	2.63	0.81	0.027	0.19	36.

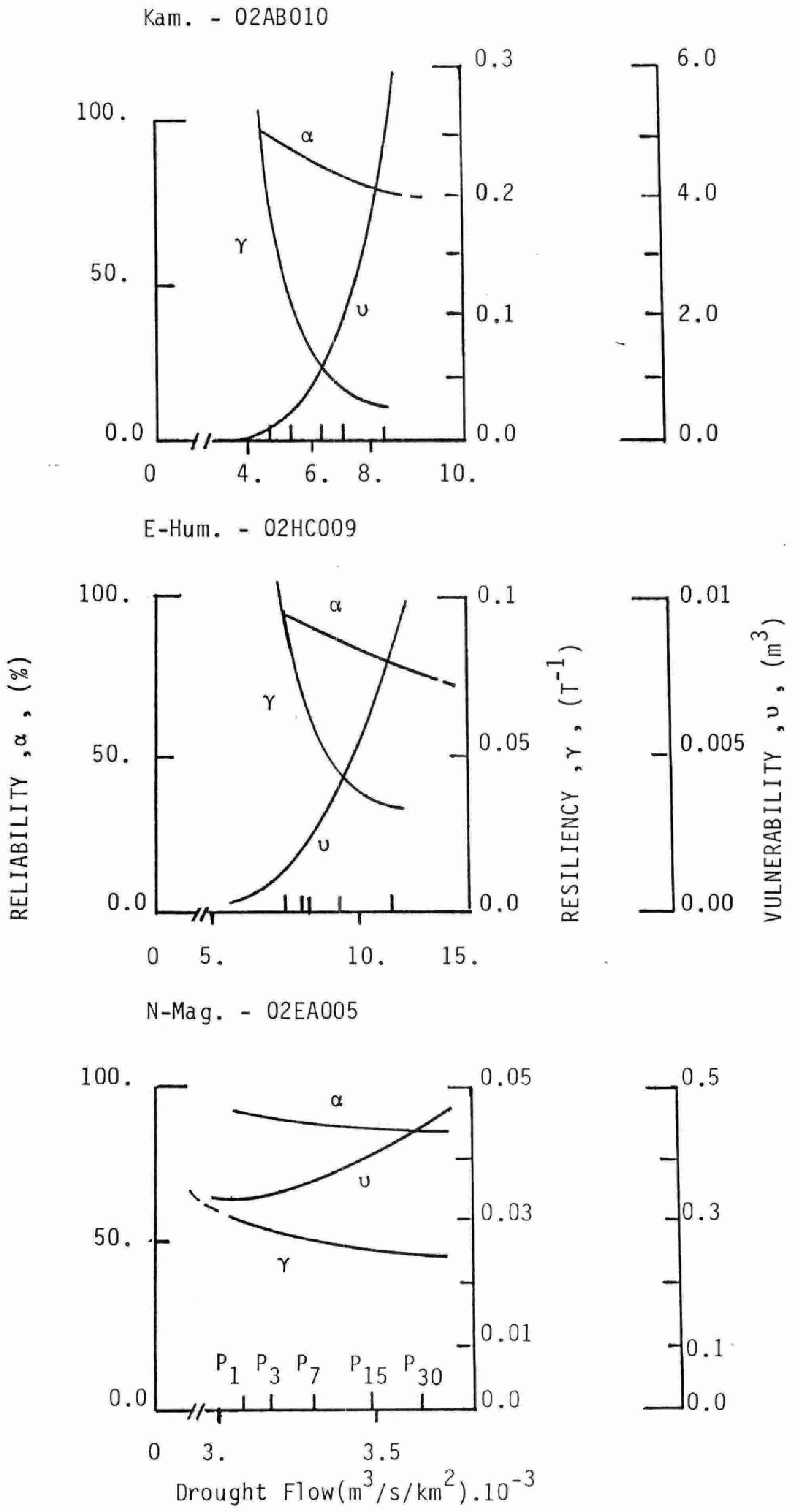


Figure 5. Performance Evaluation of River System Under Characteristic Drought Flow(X_0).

TABLE 4: RIVER SYSTEM PERFORMANCE: DESIGN FLOW

Reliability: $\alpha = P\ [X_t \geq 7Q_T]$

POLICY	KAMINISTIQUIA (%)	N-MAGNETAWAN (%)	NOTTAWASAGA (%)
$7Q_{20}$	99.7	100.0	99.6
$7Q_{10}$	99.6	99.8	99.3
$7Q_2$	93.9	94.3	94.3

Resiliency: $\gamma = P[X_{t+1} \geq 7Q_T \| X_t < 7Q_T]$

POLICY	KAMINISTIQUIA	N-MAGNETAWAN	NOTTAWASAGA
$7Q_{20}$	0.56	1.00	0.21
$7Q_{10}$	0.39	0.17	0.20
$7Q_2$	0.10	0.03	0.10

Vulnerability: $V = \Sigma\ h_k\ D_k$

POLICY	KAMINISTIQUIA	N-MAGNETAWAN	NOTTAWASAGA
$7Q_{20}$	0.02	0.00	0.003
$7Q_{10}$	0.04	0.003	0.003
$7Q_2$	0.50	0. 08	0.040

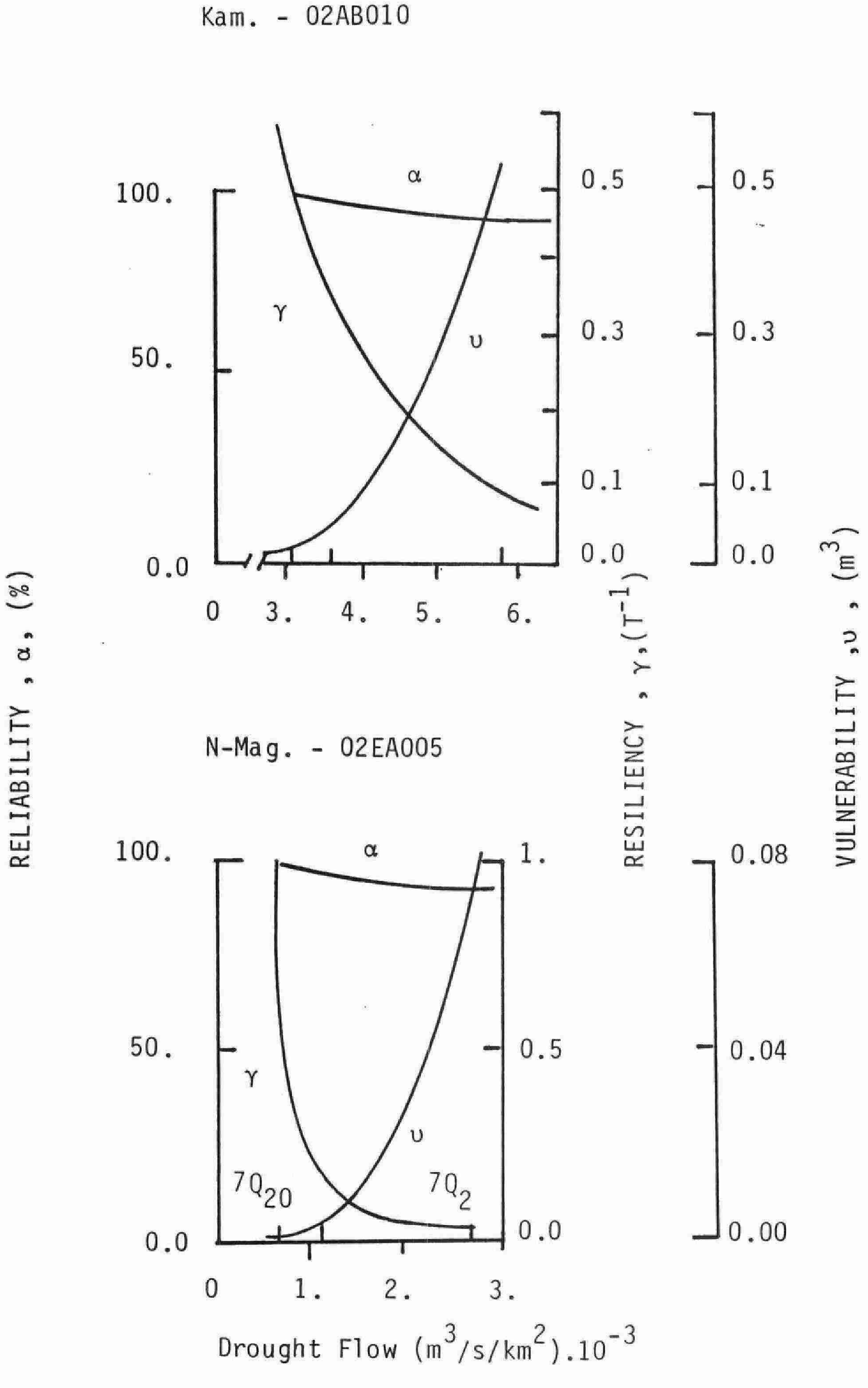


Figure 6. Performance Evaluation of River System Under Drought Flow Design($7Q_T$)

CONCLUSION

A frequency anaylsis of annual average streamflow yields for the province has identified Normal Distributions for both the natural and regulated streamflows. The non-parametric probability model, Gumbel Extremal Type 3 Distribution, is adopted for evaluating extreme drought flows in Ontario. Characteristic drought flows have been derived for gauged stations with corresponding frequency curves for specified return periods. Probability distribution, on a spatial basis, for the consecutive 7-day drought flow designs $7Q_2$, $7Q_{10}$ and $7Q_{20}$ were shown to be negatively skewed, indicating non-normality.

A computer-intensive statistic, using the Boothstrap technique, has been used to develop site specific empirical non-parametric joint distributions for the characteristic drought flow, X_0, and the scale parameter, a, of the Gumbel Type 1 Model. The distributions are bounded, but adequately described the uncertainties associated with these parameters.

Performance evaluations for selected rivers in Ontario, based on the characteristic drought flows and assigned drought flow designs 7_2, $7Q_{10}$ and $7Q_{20}$ have demonstrated satisfactory performance statistics α, γ and v. The reliabilities were satisfactory in all cases except that reliability by itself is not a sufficient statistic to evaluate the river system performance. The resiliency and vulnerability, in addition, showed marked changes with differing policies.

In the case of the characteristic drought flows, the vulnerability increases and the resiliency decreases with an increase in days of the defined drought sequence. This implied that although the magnitude of flow to recover from failure may not be large, the resiliency nonetheless is critical; due mainly to the length of duration of the consecutive days of failure once a failure occurred. The resiliency factor is critical to both the southern and northern rivers under characteristic drought flow conditions.

Management decision was examined utilizing drought flow designs projected to meet specific needs of wasteload assimilation. Significant improvements in the performance evaluation of the rivers were achieved. Less improvement was however observed for system performance between the policies $7Q_2$ to $7Q_{10}$, as compared to values between policies $7Q_{10}$ and $7Q_{20}$ where a greater degree of tolerance were achieved. That is, the degree of vulnerability was reduced markedly and the duration of consecutive days of failure once a failure occurred, reduced to tolerable durations. Some differences were observed between streamflow stations in the north where both vulnerability and resiliency would be of concern as compared to the stations in the south, where resiliency would have the greater impact on the system especially to water quality. The current Ministry's

guideline, on drought flow design, $7Q_{20}$, demonstrated excellent system performance evaluation at most sites. In that the streamflow performance for wastewater assimilation, showed high reliability and tolerable resilience. Greater susceptibility to shock of failures and damages to the river once failure occurred are therefore more critical especially in the characteristic drought flow ranges. Suitable management decision on design policy for wastewater assessment could avert likely potential impacts of drought to water quality.

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